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Reducing Defects using DMAIC Methodology in an Automotive Industry

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ABSTRACT

Quality is when it meets the wants and expectations of customers or even exceeds them. Every company must raise the quality of its current products and services. A complete and adaptable approach for establishing, maintaining, and maximizing company success is Six Sigma. Define, Measure, Analyze, Improve, and Control (DMAIC) is one of the tools used to implement Six Sigma. Based on observations of one of the automotive companies in Indonesia that produces colt diesel trucks, defective products were found in the welding process at 5%, while the defect tolerance set by the company must be below 3%. The research contribution is increasing sigma values by reducing the number of defects. This research was conducted to determine the process capability based on product defects with the Six Sigma DMAIC method approach, then to find out the proposal for implementing quality control by analyzing the causes of defects in the production process and then looking for continuous improvement with the 5W+1H concept. The improvement was made to decrease the DPMO value of 4.496 and increase the sigma value of 0.19. This study demonstrates how the Six Sigma DMAIC approach can improve the quality of the cabin production process for the part side outer pillar LH. This case can help company managers apply Six Sigma methods to solve complex problems in other processes.

1. Introduction

Several companies create products that appeal to consumers based on specifications like type, quality, and shape. Superior product quality will increase consumer satisfaction (M.T. Pereira et al., 2019). If a company can produce high-quality products and competitive prices, then the company will be able to dominate the market and compete in increasingly high business competition (Firmansyah & Yuliarty, 2020). Businesses that put a high priority on quality will also gain the trust of the market. As a result, quality control is done to ensure high-quality products (Costa et al., 2017). Quality control is based on quality standardization within a company (Raja Sreedharan V et al., 2018).

One of the automotive industry companies in Indonesia that produce various types of commercial vehicles includes Colt Diesel, FUSO, and Maru trucks. The product targeted in selecting this quality improvement is the Colt Diesel product. This product was selected because, between January and March of 2022, the Colt Diesel product has the highest production volume (88%). The production flow of Colt Diesel truck products starts from the painting, welding, assembly and quality control processes. Cabin components are products from the welding process, as seen in Fig. 1. These cabins are produced by assembling and welding several components according to their type and model. In January to March 2022, the total production of cabin products was 9,289 units, however there were 471 units or 5% of cabin product units were defective. And defective products were found greater than the defect tolerance allowed by the company, which was 3%. Defective products are products obtained from the production process that do not meet the specified quality standards. The percentage of defective products that exceed the standards set by the company will result in waste and reduce customer satisfaction. Therefore, cabin products of the Colt diesel type were chosen because of their improved quality. In addition, the company should use preventative measures to increase product quality and decrease the number of defective products. The company must integrate quality control into the production process as a result (Sumasto et al., 2023).

Fig. 1. Cabin Colt Diesel Trucks

Quality control is a method and a planned course of action used to achieve, maintain, and improve the quality of a product or service so that it complies with requirements and can satisfy customers (Noori & Latifi, 2018). To achieve business excellence in the automotive industry, stakeholders must provide perfect services and products by promoting the zero-defect concept (Pugna et al., 2016). The new management technique known as Six Sigma replaces Total Quality Management (TQM), which is primarily concerned with quality control through an analysis of the company's complete production system (Ahmed et al., 2020). Eliminating production errors, speeding up product production, and cutting costs are the objectives of the Six Sigma methodology (Firmansyah & Yuliarty, 2020). The Define-Measure-Analyze-Improve-Control (DMAIC) framework guides improvement actions in the Six Sigma methodology (Hakimi et al., 2018). DMAIC is a crucial process for continuous improvement toward Six Sigma targets (Fithri, 2019).

The statistical way of thinking and Six Sigma DMAIC are applied in several studies on the automotive industry's assembly process by enhancing the design of hand tools and including poka-yoke devices. As a result, both the short-term and long-term sigma levels increased, rising from 2.9 to 5.2 and 1.4 to 3.7, respectively (Pugna et al., 2016). Furthermore, research is needed to remove bottlenecks in the process and increase production by applying DMAIC, Value Stream Mapping, ANOVA, and 5S techniques in the food industry in India (Nandakumar et al., 2020). Then, research using the DMAIC and Failure Mode Effect Analysis (FMEA) methods in Small Medium Enterprise (SME) results in reduced costs and increased sigma values (Soundararajan & Janardhan Reddy, 2019). In addition, research on tire manufacturing by adopting the Six Sigma methodology and using the

DMAIC cycle, a 0.89% reduction in the work-off indicator generated by the production system resulted in savings of more than 165,000€ per year (Costa et al., 2017).

Lean manufacturing and Six Sigma techniques are used to increase efficiency (Guleria et al., 2021; Luiz et al., 2019; Mitra, 2020; Scheller et al., 2021). Due to efficiency issues or low process productivity cycles in the train carriage assembly process, there has been a significant reduction in waiting time, increased value-added time, and a significant decrease in non-value-added time (Daniyan et al., 2022). In addition, the Six Sigma DMAIC process was implemented (Kregel et al., 2021; Padmarajan & Selvaraj, 2021; Ploytip Jirasukprasert et al, 2014; Putri et al., 2018; Sharma et al., 2018). One example is the Indian rubber weather strip manufacturer. After using the Six Sigma approach, the number of defective goods was reduced, resulting in cost savings, and the Sigma level increased from 3.9 to 4.45 in three months (Mittal et al., 2023). Enhancing the Six Sigma methodology using simulation techniques can be used as further research with case studies of the automotive industry (Ahmed et al., 2020).

This research provided suggestions for improving control and quality using the Six Sigma Method through the DMAIC stages and several Quality Control Tools. However, the DMAIC method is commonly used to increase the sigma level and reduce the number of defective products. This research focuses on the improvement stage, which improves humans, methods, materials, and machine factors. Finally, this research contributes to increase sigma values continuously by reducing the number of defects in the welding process of colt diesel truck cabins.

2. Method

2.1 Define Phase

The initial stage in DMAIC is the define stage. This stage aims to select defective components in the colt diesel cabin product. At this stage, it is necessary to know the flow of materials from suppliers to customers by creating a SIPOC (Supplier, Input, Process, Output, Customer) diagram (Araman & Saleh, 2023; Desai, 2016). Based on this, the side outer pillar LH components were classified by Critical to Quality (CTQ) defect type (Table 3), and a Pareto diagram (Fig. 5) was developed to show the largest and most significant impact of defects.

CTQ is an element of the process that influences achieving the desired quality (Solanki & Desai, 2020). In determining CTQ, interviews are conducted to determine customer requirements so that the wants and needs of customers can be identified, both internal and external. This diagram is made to find out the potential or dominant CTQ that will be selected by stratifying the data into groups from the largest to the smallest so that it can find out more easily which projects are more dominant in terms of the level of problem and which will later be determined as research objects then make a Pareto diagram to determine the priority to be selected (Sumasto et al., 2023).

2.2 Measure Phase

The measuring phase is the second stage for measuring and calculating data obtained from problems that occur in the company.

1) Making a p-control chart by calculating the proportion of defects where there are discrepancies or deviations with the Center Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) values can be seen in equation (1), (2), and (3) (Mishra & Sharma, 2014). Then knowing whether the proportion of types of defects is on the Side Outer Pillar LH part is still within control limits or not.

$$UCL = p + 3\sqrt{\frac{p\,(1-p)}{n}} \tag{1}$$

$$CL = \frac{\sum x}{\sum n} \tag{2}$$

$$LCL = p - 3\sqrt{\frac{p\,(1-p)}{n}} \tag{3}$$

2) Perform DPMO calculations and sigma value results.
The DPMO calculation stages are Defect Per Unit (DPU), Total Opportunity (TOP), Defect per Opportunity (DPO), and DPMO can be seen in formulas (4), (5), (6), and (7) (C.R & Thakkar, 2019).

$$DPU = \frac{Number\ of\ defective\ products}{Production\ quantity} \tag{4}$$

$$TOP = production\ quantity\ x\ probability\ of\ defect \tag{5}$$

$$DPO = \frac{number\ of\ product\ defects}{TOP} \tag{6}$$

$$DPMO = DPO\ x\ 1.000.000 \tag{7}$$

2.3 Analysis Phase

The analysis phase is followed by making a fishbone diagram of the highest type of defect to analyze and determine the root causes of the problem of the occurrence of these defects (Noori & Latifi, 2018).

2.4 Improve Phase

The improvement phase has a goal for problems that occur by carrying out a solution or proposed improvement to reduce the types of defects that occur and increase the sigma value. Things to do in the improvement phase are making suggestions for improvements with 5W+1H analysis and implementing the results of the 5W+1H.

2.5 Control Phase

This control phase is the last in DMAIC, which is carried out to control the process from the initial goal so that problems that have occurred do not recur in the future. In addition, a re-calculation of the defective product was carried out to compare with the current condition.

3. Results and Discussion

The stages of implementing the Six Sigma and DMAIC methods are as follows:

3.1 Define Phase

1) Selection of Six Sigma quality improvement projects

The Six Sigma project selection results will be used as a quality improvement project by prioritizing problems often occurring in the Colt diesel welding process. This selection is based on problems in the company because there are defective products above the target determined by the company. The initial step is to select the component with the most defects in the cabin product. Most of these defective products are found in the welding production process for cabin products with the work order, as shown in Fig. 2.

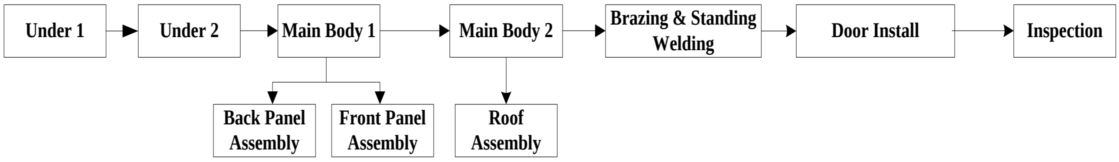


Fig. 2. Production Flow of Welding Process for Cabin Product

Each process in the cabin product production flow (Fig. 2) has a different number of defects. Based on data on defective products from January to March 2022 (Table 1), the highest percentage of defects was obtained at the main body 1 process, where 269 units, or 57%, were found.

Table 1. Number of Defects for Each Process in the Welding for Cabin Products in January to March 2022

Process Name	Month (Unit)			Number of Defects (Unit)	Defect Percentage	Cumulative Percentage
	January	February	March			
Under 1	14	6	4	24	5%	5%
Under 2	40	22	29	91	19%	24%
Main Body 1	98	80	91	269	57%	82%
Main Body 2	35	14	23	72	15%	97%
Door Install	5	7	3	15	3%	100%
Total	192	129	150	471		

The next step is to select the component from the cabin product with the highest number of defects in the main body process 1. In Table 2, the component with the highest number of defects is the part side outer pillar LH (Fig. 3), which has a total of 133 defects.

Table 2. Number of Defects in Main Body 1 Component During January to March 2022

Component Name	Month (Unit)			Number of Defects (Unit)
	January	February	March	
Side Outer Pilar LH	52	33	48	133
Side Outer Pilar RH	25	29	31	85
Back Panel	7	6	4	17
Reonf Rear Panel	4	5	2	11
Bracket Snorkel	3	1	1	5
Wind Shield	1	1	0	2
Pillar Front LH	2	2	1	5
Pillar Front RH	3	2	2	7
Panel Front	1	0	2	3
Rail Roof Front	0	1	0	1
Total	98	80	91	269

Fig. 3. Part Side Outer Pillar LH

2) SIPOC Diagram

To obtain an early understanding of the activities associated to the process that need to be enhanced. Thus, a Supplier, Input, Process, Output, and Customer (SIPOC) matrix is required. The SIPOC diagram in Fig. 4 displays the whole supply chain, from order to supply. Improvements to reduce the quantity of defective products are implemented at the process stage, specifically during the welding process that produce cabin products.

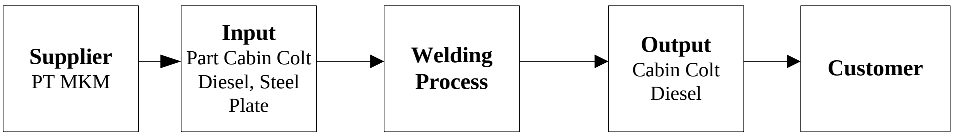
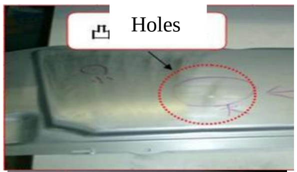
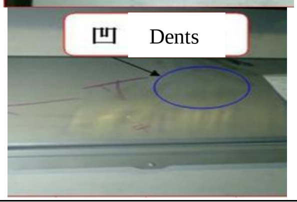


Fig. 4. SIPOC Diagram

3) Determine Critical to Quality (CTQ)

In the CTQ, the types of defects that have the most potential or influence on cabin products, especially for side outer pillar LH components, can be seen in Table 3.

Table 3. Identification of types of defects in the welding process for cabin products

Defect Name	Figure	Description
Spot Not Good		Spot welding results that are not up to standard; for example, there are white spots, or the size of the spot diameter is not up to standard.
Bumps		The type of defect in which a hole in the spot-welding results in misses another part that is not a place for a spot to be made
Holes		The type of defect that is convex towards the outside of the material's surface.
Dents		A dent is a defect characterized by a concavity towards the inside of the material's surface.

Based on the results of identifying the defects obtained on the side outer pillar LH, one type with a significant impact will be taken as a top priority and followed up on the causes of defects in the side outer pillar LH. According to Fig. 5, dents are the highest percentage of component types that cause defects.

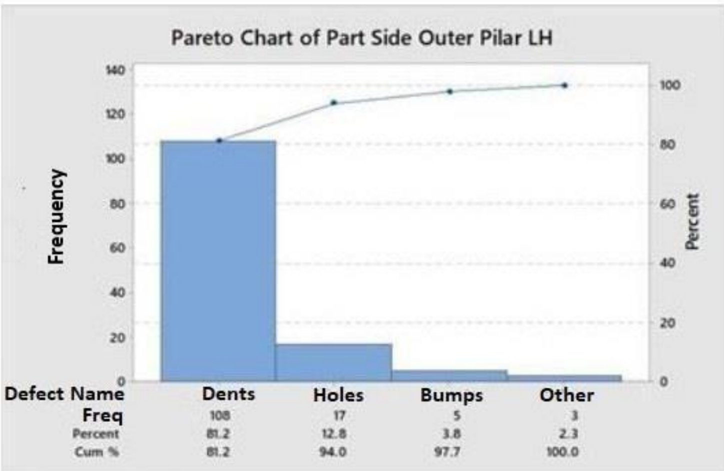


Fig. 5. Pareto Chart of Defects Side Outer Pillar LH Colt Diesel

3.2 Measure Phase

Control charts are created at this quality measurement phase, and DPMO and sigma values are calculated. At this stage, the type of defect that will be repaired is a dent because this type of defect is the most common based on the Pareto diagram (Fig.5).

1) Measurement with P-Control Chart

The control chart aims to measure the proportion of nonconformities and control the proportion of units that do not meet specification requirements. In this research, a p-control chart is used because the sample taken for each observation varies with each number. The Center Line (CL), Upper Control Limit (UCL), and Low Control Limit (LCL) are calculated using data on production quantities and defect numbers from January to March 2022 by using equations (1), (2), and (3). After knowing these values, the data is plotted into a control chart. If there is data that goes outside the control limits, revisions must be made to stabilize the process. The recapitulation table for the p-control chart calculation can be seen in Table 4:

Table 4. The Calculation of P-Control Chart Type of Defect Dent Part Side Outer Pillar LH Colt Diesel Truck

Date	Production (Unit)	Defect (Unit)	Proportion	CL	UCL	LCL
January 3-8, 2022	1169	16	0.013	0.011	0.021	0.002
January 10-15, 2022	533	3	0.005	0.011	0.025	-0.002
January 17-22, 2022	733	4	0.005	0.011	0.023	-0.022
January 24-31, 2022	1206	21	0.017	0.011	0.020	0.002
February 2-6, 2022	607	4	0.006	0.011	0.024	-0.001
February 8-13, 2022	384	3	0.007	0.011	0.028	-0.004
February 14-19, 2022	750	11	0.014	0.011	0.023	-0.000
February 21-26, 2022	663	10	0.015	0.011	0.024	-0.000
March 1-5, 2022	716	5	0.006	0.011	0.023	-0.000
March 7-12, 2022	1078	25	0.023	0.011	0.021	0.001
March 14-19, 2022	448	3	0.006	0.011	0.026	-0.003
March 21-25, 2022	594	2	0.003	0.011	0.024	-0.001
March 28-31, 2022	408	1	0.002	0.011	0.027	-0.004
Total	9,289	108	0.129			

Based on the results of the UCL and LCL calculations, one proportion data is out of the control limit or out of the UCL, namely the proportion data for March 7-12, 2022. Hence, the data needs to be revised again so that there are no deviations and remains at the control limit or control by eliminating the data whose number of defects exceeds the control limit. Based on the results of the recalculation on the p control chart, which can be seen in Fig. 6, it was found that the proportion data was all within the control limits, so no further revision was necessary.

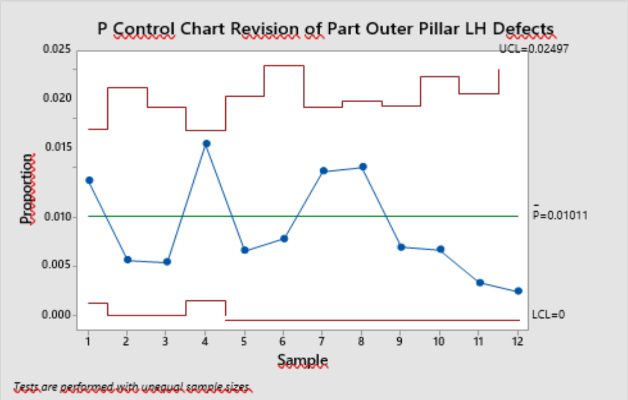


Fig. 6. P-Control Chart Revision of Part Outer Pillar LH Defects

2) Determine the value of Defect Per Million Opportunities (DPMO)

The steps to determine the DPMO value are to use equations (4), (5), (6) and (7):

a. Determine the value to be measured. The value to be measured is the same as the sample size of cabin production in January–March 2022, which is 9,289 units.
b. Determine the value of Opportunity (OP).

The highest type of defect for cabin products based on CTQ results is dents.

c. Number of defects
Defective products on the side outer pillars of the LH cabin are 108 units.

d. Calculate Defect per Opportunity (DPO)
The calculation of defects per unit is obtained by comparing the number of defective products with total production, so the DPO value is 0.01162.

e. Calculating DPMO
Based on the DPMO calculation results, the number of defects per one million opportunities on the outer side of the LH Cabin is 11,626 units.

3) Determine Sigma Level

The sigma level is calculated by converting the company's DPMO value to the sigma value table. Based on the sigma table, with a DPMO value of 11.626, the company's sigma level is currently at 3.76.

3.3 Analyze Phase

This stage was carried out to determine the factors causing the defect problem on the side outer pillar LH by using one of the quality controls tools, the fishbone diagram, which can be seen in Fig. 7. The fishbone diagram was compiled based on the brainstorming results with the cabin product welding process's operator, foreman, leader, and supervisor. Based on the brainstorming results, the causes of dent defects were identified as human, material, method, and machine factors. The human factor is the need for more accuracy and responsibility from operators during the manufacturing process, such as not adhering to Standard Operation Procedures (SOP) because they are only concerned with production targets and accuracy, resulting in careless handling of parts.

The causes of defects are due to method factors, specifically the incorrect placement of the SOP and the irregular placement of the material, which causes the material to collide with iron and cause dent defects in the components. Material-related dent defects are caused by pallets that lack protectors, allowing the material to collide directly with the iron pallet. Lack of machine maintenance causes defects in components because the claim jig is too sharp and the wind pressure is too high.

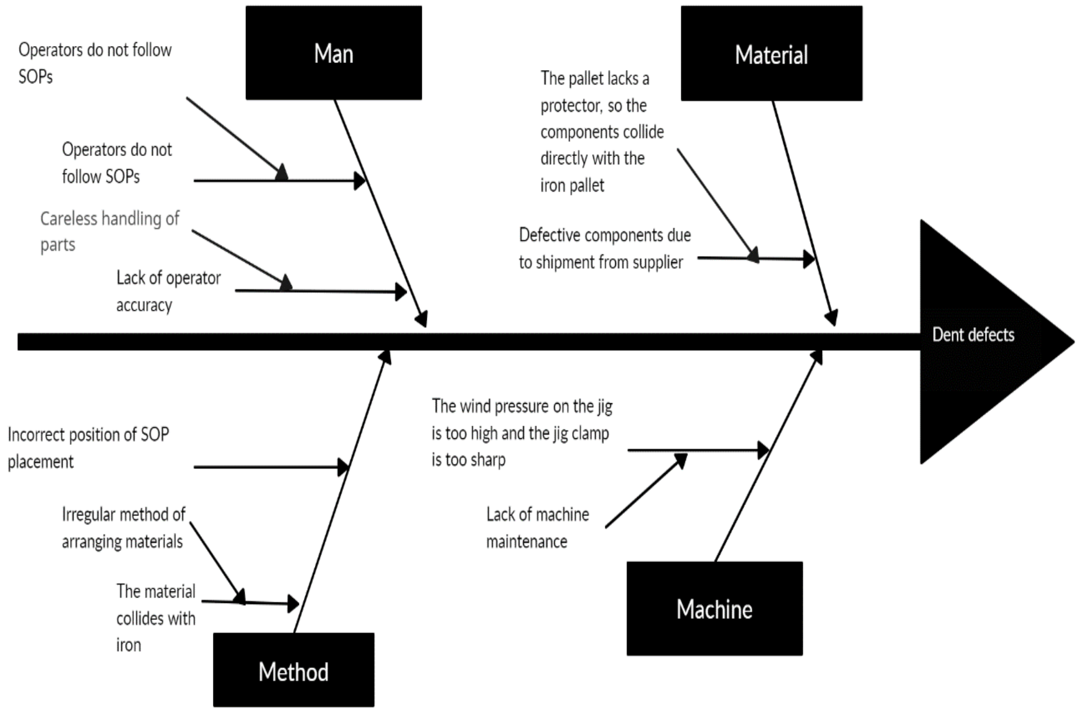


Fig. 7. Fishbone Diagram for Dent Defect Types on Colt Diesel Part Side Outer Pillars LH

3.4 Improve Phase

The fourth stage of the DMAIC method is the improvement stage, which aims to provide suggestions for improving the causal factors identified in the fishbone diagram. The improved step is carried out using the 5W+1H method, as seen in Table 5.

Table 5. Improvement Plan with the 5W+1H Method

Factor	What	Why	Where	Who	When	How
	Main Objective	Usability Reasons	Location	People	Process Order	Method
Method	Standard Operation Procedure (SOP) not visible at work	In order not to be mistaken in the production process	Area welding Colt Diesel	Foreman	During the production process	Include SOP to be visible to all operators
	Collied with iron material/part that has been processed	Regular placement and reduces defects in the parts that occur	Area welding Colt Diesel	Supervisor, Foreman, Operator	During the production process	Design and build a special stand for part placement
Machine	The wind pressure on the jig is too high and the clamp jig is too sharp	Not to damage the material on the cabin product	Area welding Colt Diesel	Maintenance, Product Engineering, Quality	Once a month	Make frequent periodic checks and speed up the handling of the machine
Man	Operators do not follow SOP	Operators must be aware and remember the job	Area welding Colt Diesel	Foreman	During the production process and	Make frequent supervision of operator performance,
		Description are given	Area welding Colt Diesel		Before working on the production process	Controlling with operator checklists
	Lack of accuracy on the operator	Reduce damage to parts	Area welding Colt Diesel	Foreman and line keeper	After working hours are completed	Briefings or reminders related to this to be more responsible and thorough at work
Material	Defect part from the supplier	The quality of the material is maintained	Area welding Colt Diesel	Vendor	Before delivery and goods are placed on pallets and protectors are replaced once a month	Doing follow-ups, making more frequent checks, and making agreements and also punishments for vendors

Based on the improvement plan using the 5W+1H method, the implementation of the improvements to be carried out are:

1) Man Factor

Based on fishbone analysis, one of the causes of defects in the Side Outer Pillars LH from human factors is a lack of responsibility and accuracy towards operators who can be at risk of undesirable things. Therefore, to reduce defects due to human factors is to tighten supervision of operator performance and provide briefings related to production and control processes by filling in daily checklists for operators.

2) Method Factor

The cause of the problem of dent defects in the method factor is the inappropriate placement of the SOP and the absence of a special stand for part placement. As a result, improvements were made by improving the placement of the SOP, as shown in Table 6, and designing a special stand for placing parts, as shown in Table 7.

Table 6. Provide SOP in the welding process area

Provide SOP in the welding process area	
Before Improvement	**After Improvement**
	

Table 7. Design and Build Stands for Placing Parts

Design and Build Stand Part Outer Pillar LH Colt Diesel		
Before Improvement	**After Improvement**	**Design Special Stand Parts**
		

3) Material Factor

The issue with the material factor is that suppliers supply defective raw materials due to a lack of pallet protectors, which causes materials to collide with iron pallets and a lack of checking for materials. So that it affects the quality of the product produced, the action taken is to replace the protector periodically and tighten checks on raw materials. Table 8 shows the results of these actions.

Table 8. Improvement of Material Factors by Attaching Protectors

Attaching the Protector to the Pallet	
Before Improvement	**After Improvement**
 	

4) Machine Factor

The problem with the engine factor is the need for more maintenance of work tools so that the clamp jig is too sharp and the wind pressure on the jig is too high, affecting the product quality. Actions taken to overcome problems with engine factors are tightening checks on working tools once a week.

3.5 Control Phase

At this stage, evaluation and control will be carried out on the improvements made to the welding process for the side outer pillar parts. Based on the CTQ results, there are four types of defects, including no good spots, bumps, holes, and dents. However, the most common type of defect is dents. So, the type of dent defect will be analyzed at the measurement stage. The control stage is carried out to determine the percentage of defects from June until July 2022 using the p-control chart, DPMO value and sigma value. The p-Control chart functions to see whether the company's quality control is under control. The p-Control chart has the benefit of helping control production quality and can provide information about when and where the company needs to make quality improvements.

Based on the control results, there were 171 units of defective products. The DPMO calculation obtained was 7,130 units, resulting in the company's sigma level after implementation at 3.95. After the improvements, there was an increase in the sigma level, which shows that there were process variations, so the product quality of the side outer part of the LH pillar increased. Improvements have succeeded in improving quality and can be applied continuously. In Table 9, there is a comparison of DPMO and Six Sigma values before and after improvement. There is a comparison of the percentage of defects in the welding process and the side outer pillar LH with the results that both have decreased, as shown in Table 10.

Table 9. Comparison of DPMO and Six Sigma Values Before and After Improvement

Value	Before Improvement	After Improvement	Percentage Comparison
DPMO	11,626	7,130	Decrease 4,496
Six Sigma	3.76	3.95	Increase 0.19

Table 10. Comparison of Defect Percentage Values Before and After Improvement

Defect	Before Improvement	After Improvement	Percentage Comparison
Welding Process of Colt Diesel	5%	3.81%	Decrease 1.19%
Part Side Outer Pillar LH	1.43%	0.91%	Decrease 0.52%

Top management in companies is aware of the importance of quality management practices and quality improvement tools and their impact on organizational performance. Quality control is an important thing that companies must do to minimize defective products. Companies can analyze product defects using the Six Sigma method by formulating the Define, Measure, Analyze, Improve, Control (DMAIC) that occurs. Through the improvement stages of the DMAIC method, the company was able to increase the sigma value, which means there was a reduction in the number of defective products.

4. Conclusion

This paper presents a case study of quality improvement in the automotive industry, especially in the welding process for cabin colt diesel truck on the side outer pillar LH parts. Defects on the outer side of the LH pillar include spots not good, bumps, holes and dents. Meanwhile, dents are the most common type of defect. Human factors, methods, machines and materials cause dent defects. A lack of responsibility for operators following the SOP causes the human factor. The proposed improvement to minimize defects in human factors is to create a daily operator checklist. Furthermore, the causes of method factors are inappropriate SOP placement and irregular material placement. Proposed improvements to minimize the types of defects in the method factor are to regulate the placement of the SOP and design a unique stand for part placement. The cause of the engine factor is a lack of engine maintenance, so the proposed improvement is to carry out regular checks. Lastly, the material factor is the lack of protection on the pallet so that the material collides directly with the pallet iron, so the protector needs to be replaced regularly. Then, after improvements were made to reduce defects in the side outer pillar LH parts, the DPMO value was reduced by 4.496, and the sigma value was increased by 0.19. The research limitation focuses on one critical quality characteristic (CTQ), namely dent defects for the side outer pillar LH component of cabin products for colt diesel truck vehicles in the welding process.

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